Progress on the scalable lithium EUV source

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Abstract
A prior presentation [1] covered the scaling prospects of a discharge lithium EUV source to >500W usable power at the intermediate focus, with a total energy consumption of <100kW and low cost of ownership. Progress has been made on engineering aspects of the lithium source, with repetition frequency scaling recently increased to 800Hz, projecting to 60W at the intermediate focus when time-multiplexed 8X (giving a multiplexed frequency of 6.4kHz). The discharge source has a small 5g lithium inventory (including the contents of all 8 discharge units). Methods for lithium handling will be discussed, to show that it is straightforward. A review of long-term lithium interactions with metals at high temperature, mainly gathered in a space-based heat pipe program, supports expectations of long EUV source life. An outline of a development program bringing lithium rapidly to HVM will be presented.

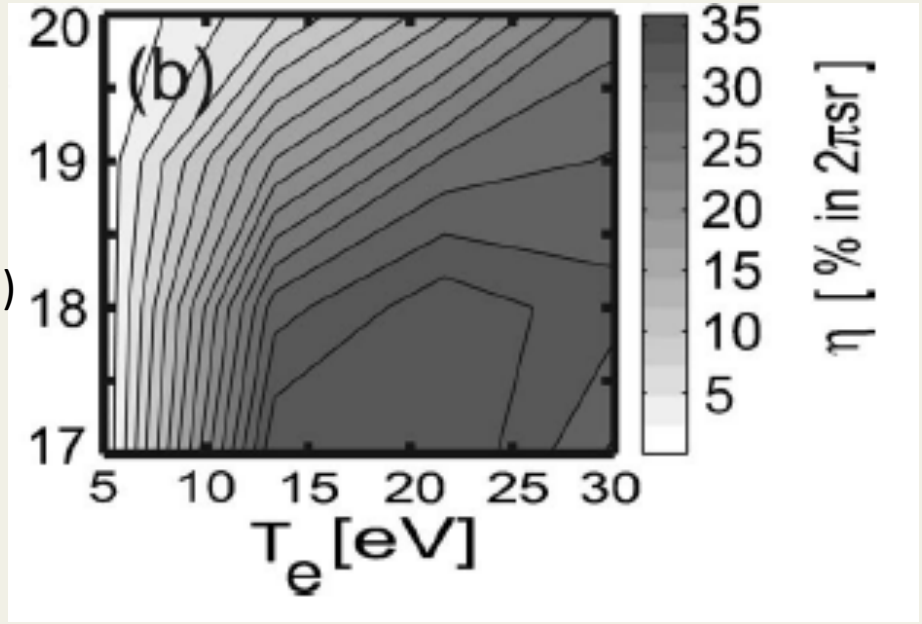
[1] M. McGeoch, Sematech Intl. Symposium on EUV Lithography, Toyama, Oct. 2013.

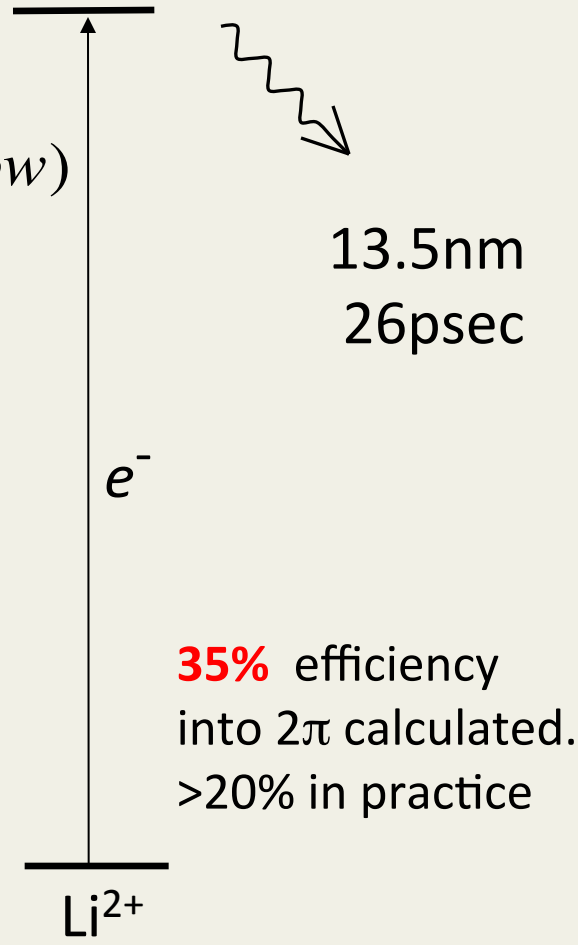
Physics Basis for Very High Efficiency of Lithium

Like sodium lamp and mercury lamp, efficiency is due to a resonance transition

$$Li^{2+} ground + e^{-}(fast) \rightarrow Li^{2+} resonance + e^{-}(slow)$$

$$Li^{2+} resonance \rightarrow Li^{2+} ground + h\nu(13.5nm)$$





35% efficiency into 2π calculated. >20% in practice

Graph from Masnavi et al. Appl. Phys. Lett. **89**, 031503 (2006)

Note that Li LPP has only 3% efficiency. Discharge >1μs necessary for 35%

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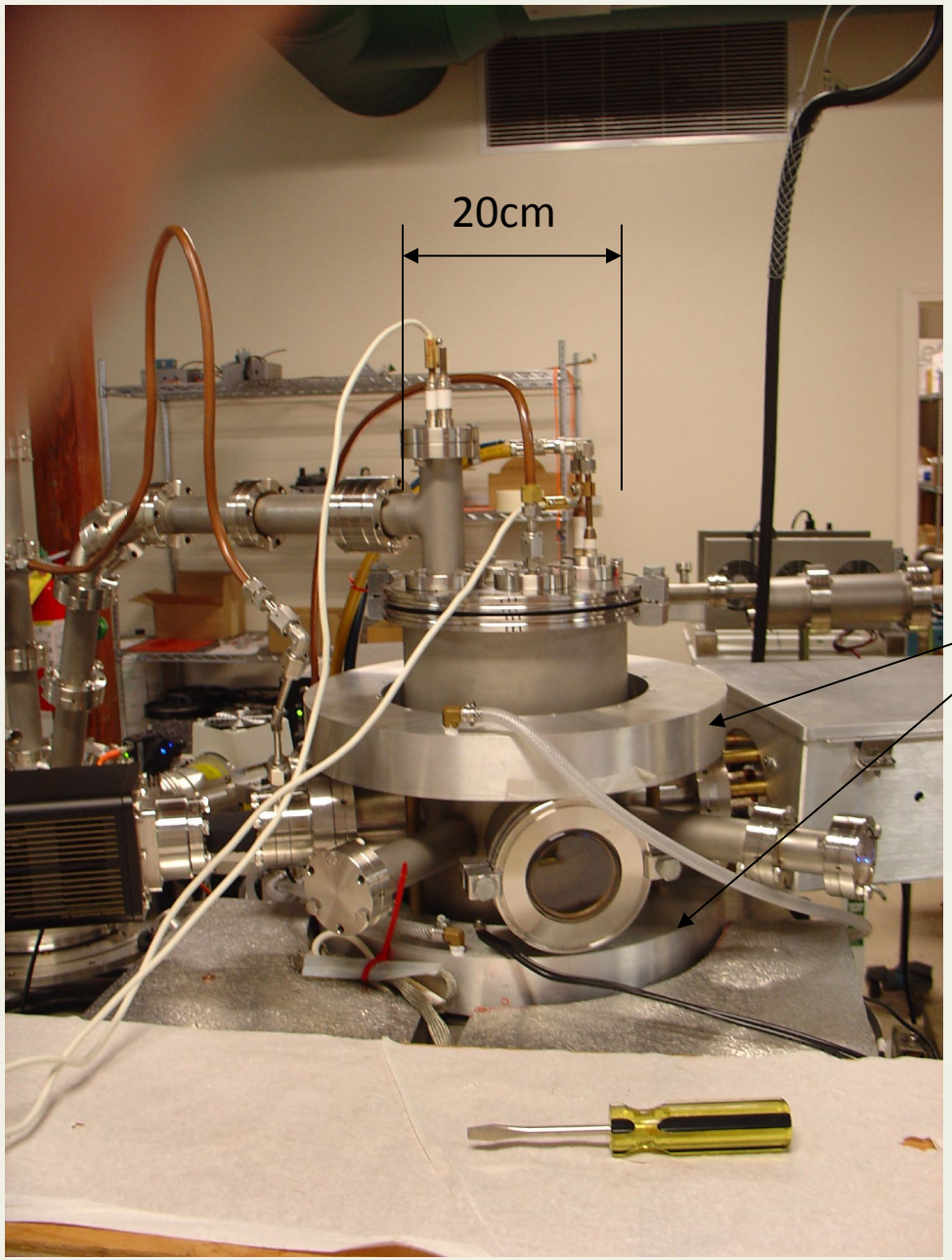
Lamp is very compact: fits within 20cm diameter chamber



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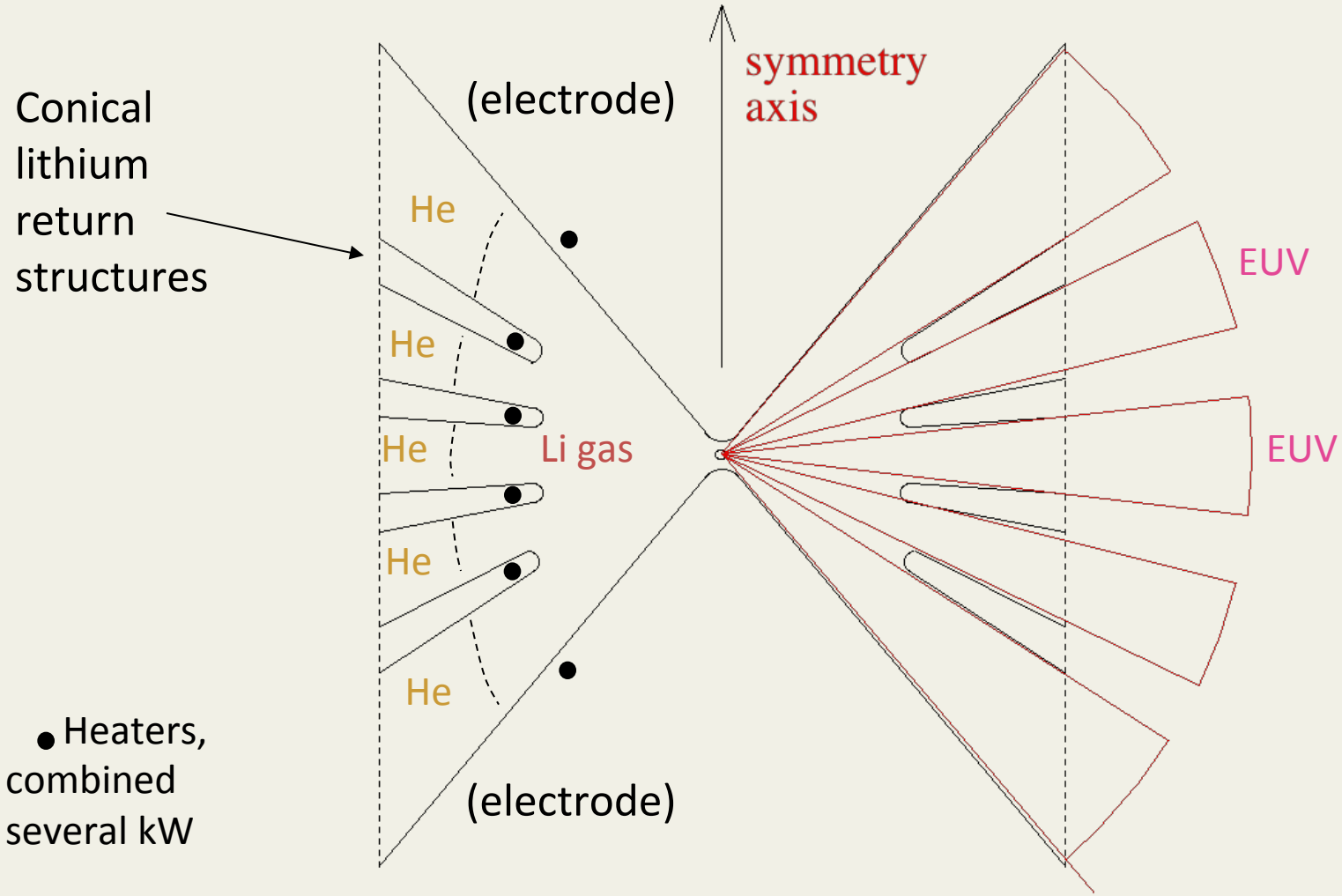
We developed a buffer gas heat pipe discharge for reliable, long term lithium control



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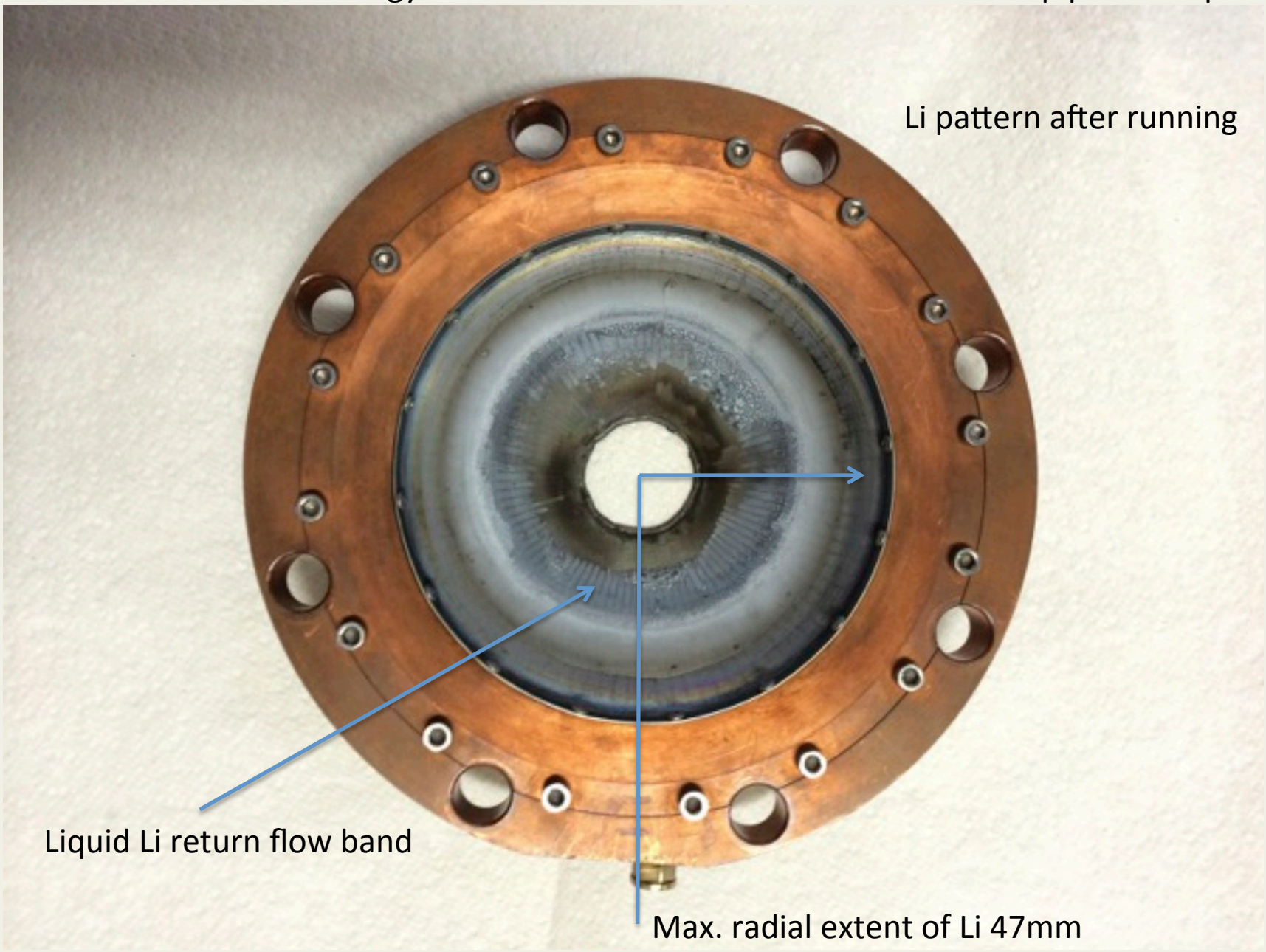
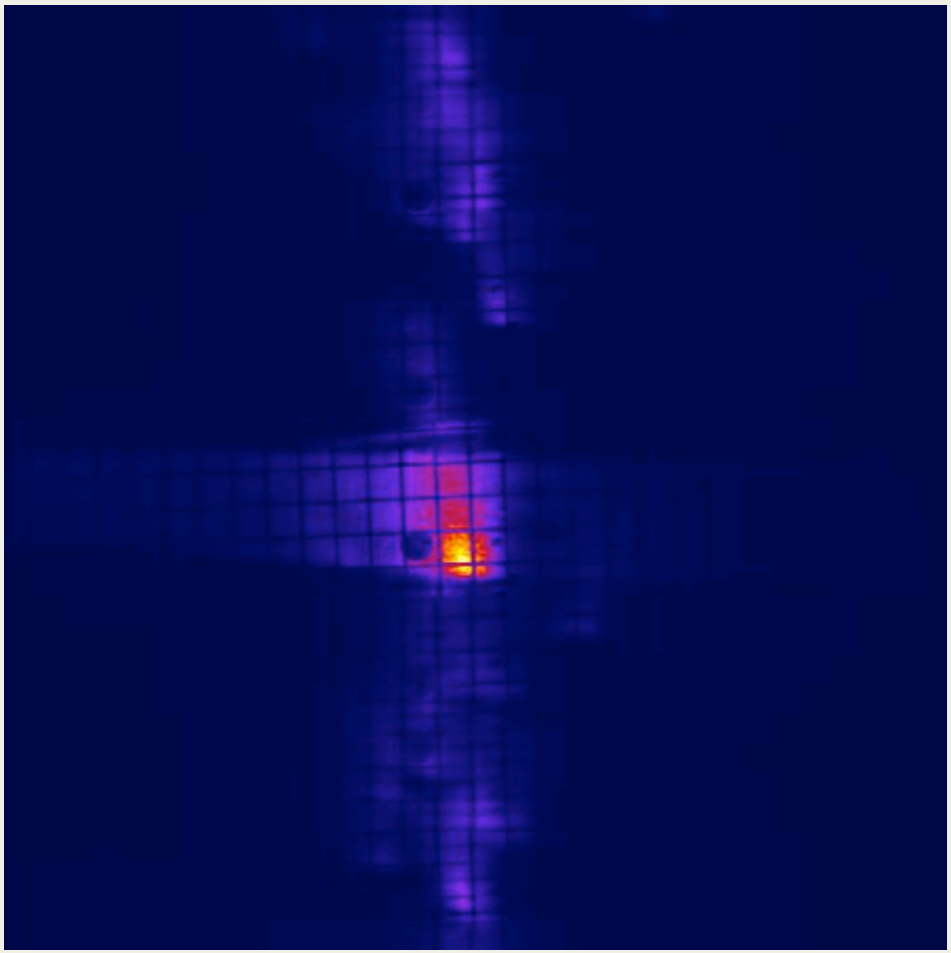
Advanced lithium technology. Containment via helium-buffered RF heat pipe is complete



Small source size in 13.5nm light



714 ± 39 μm FWHM

Stability 94μm rms

mean of 15 images

Superposition of 80 pulses at 400Hz in each pinhole camera image

65mJ/pulse/2π sr, 1.2μs FWHM, 3μs total EUV duration

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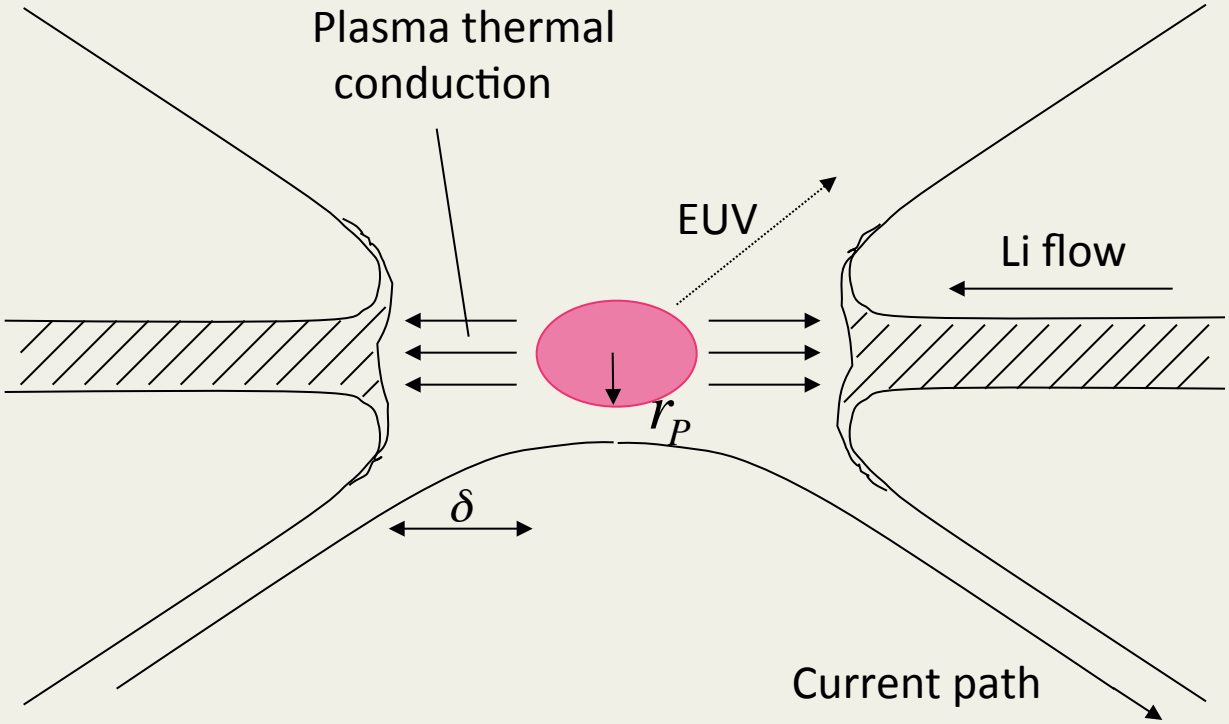
Lithium-wetted electrode tips: demonstrated capability

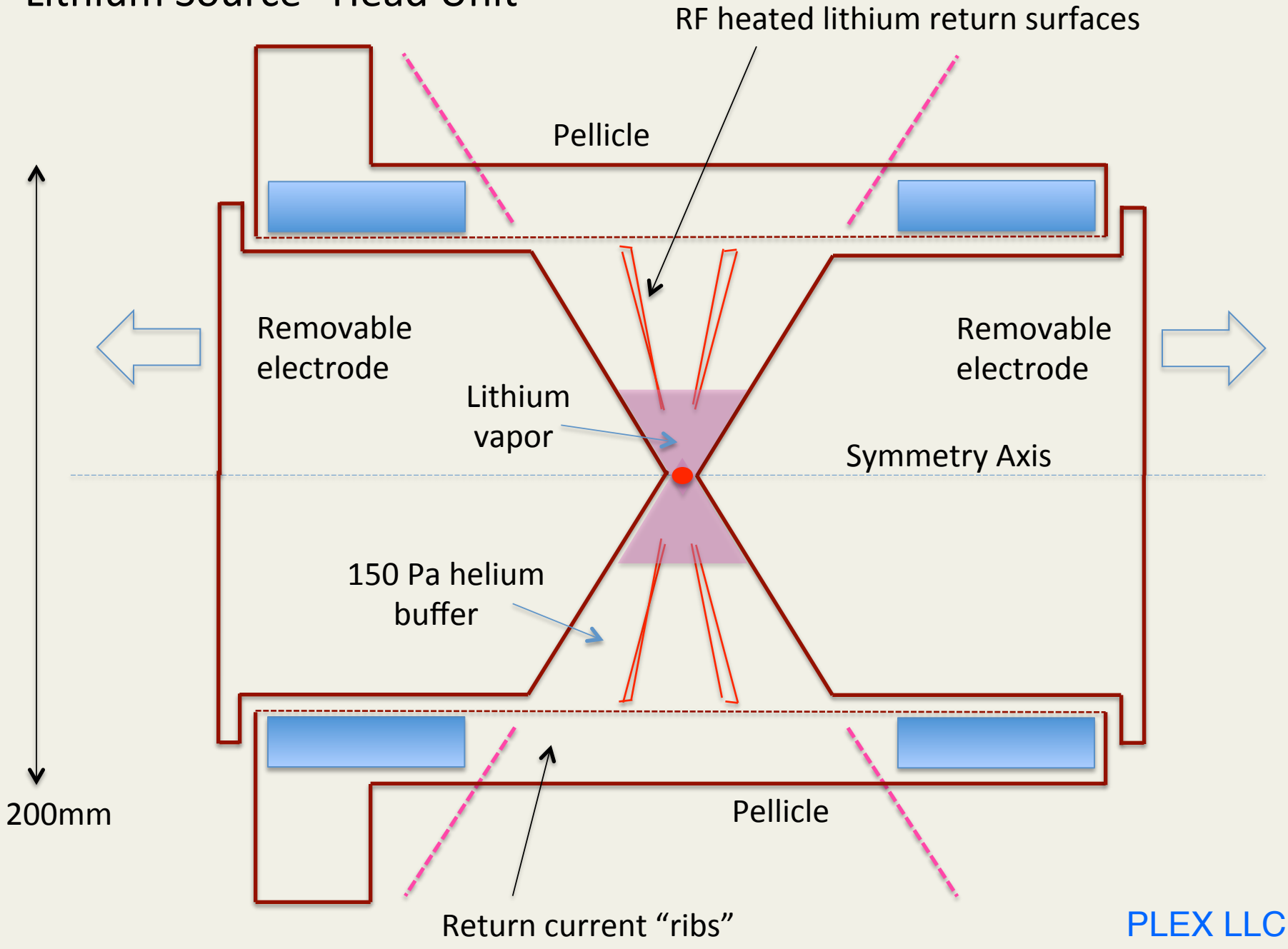


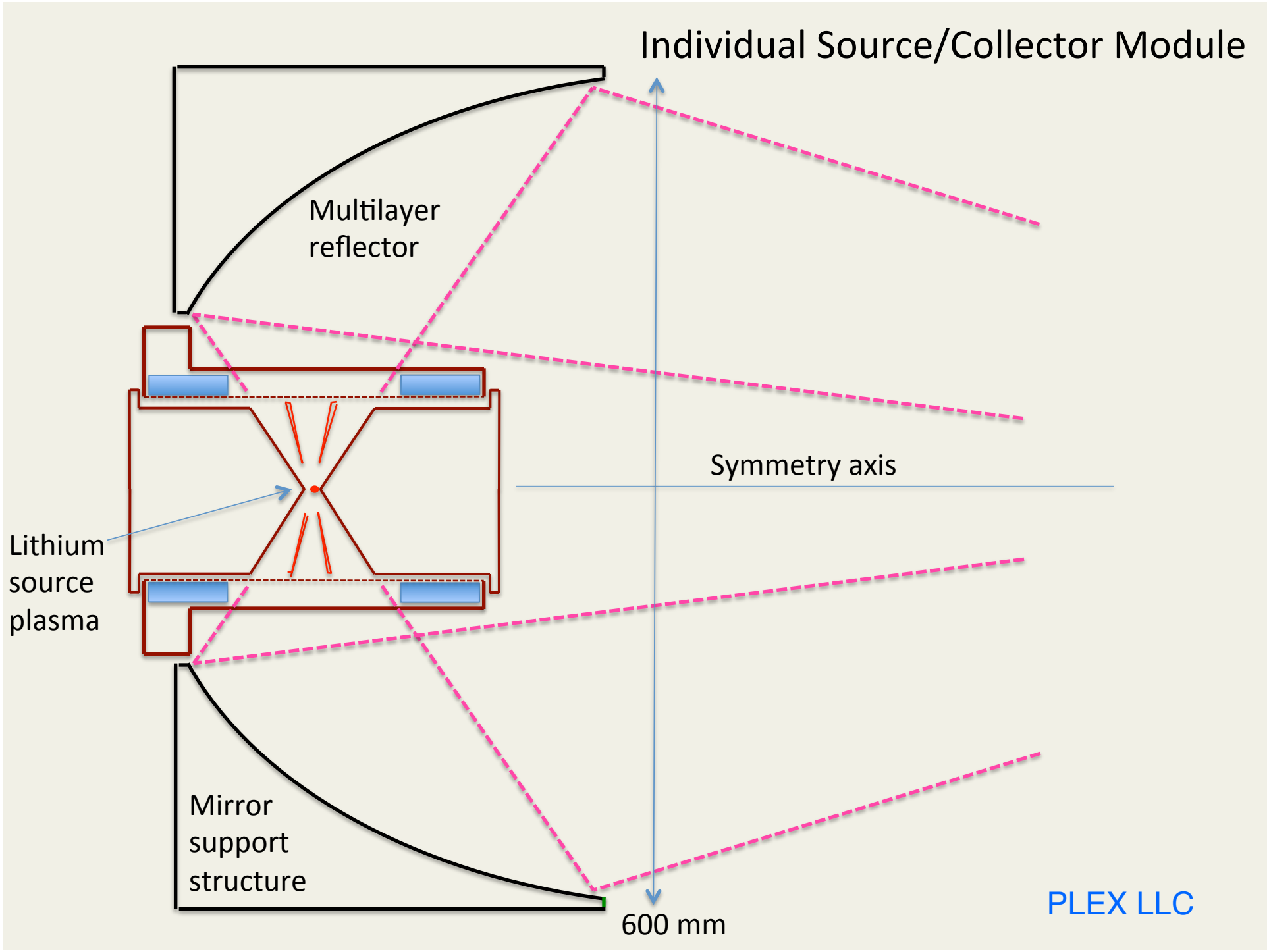
We have demonstrated Li flow with 3µsec pulses at 400Hz for >30minutes

Demonstrated 65mJ EUV from plasma at 25eV, i. e. total 200mJ/pulse/electrode

Steady state lithium flow handled 200/330 = <u>60% of 500W (IF) pulse requirement</u>

Lithium Source “Head Unit”




Individual Source/Collector Module
Multilayer reflector
Symmetry axis
Lithium source plasma
Mirror support structure
600 mm
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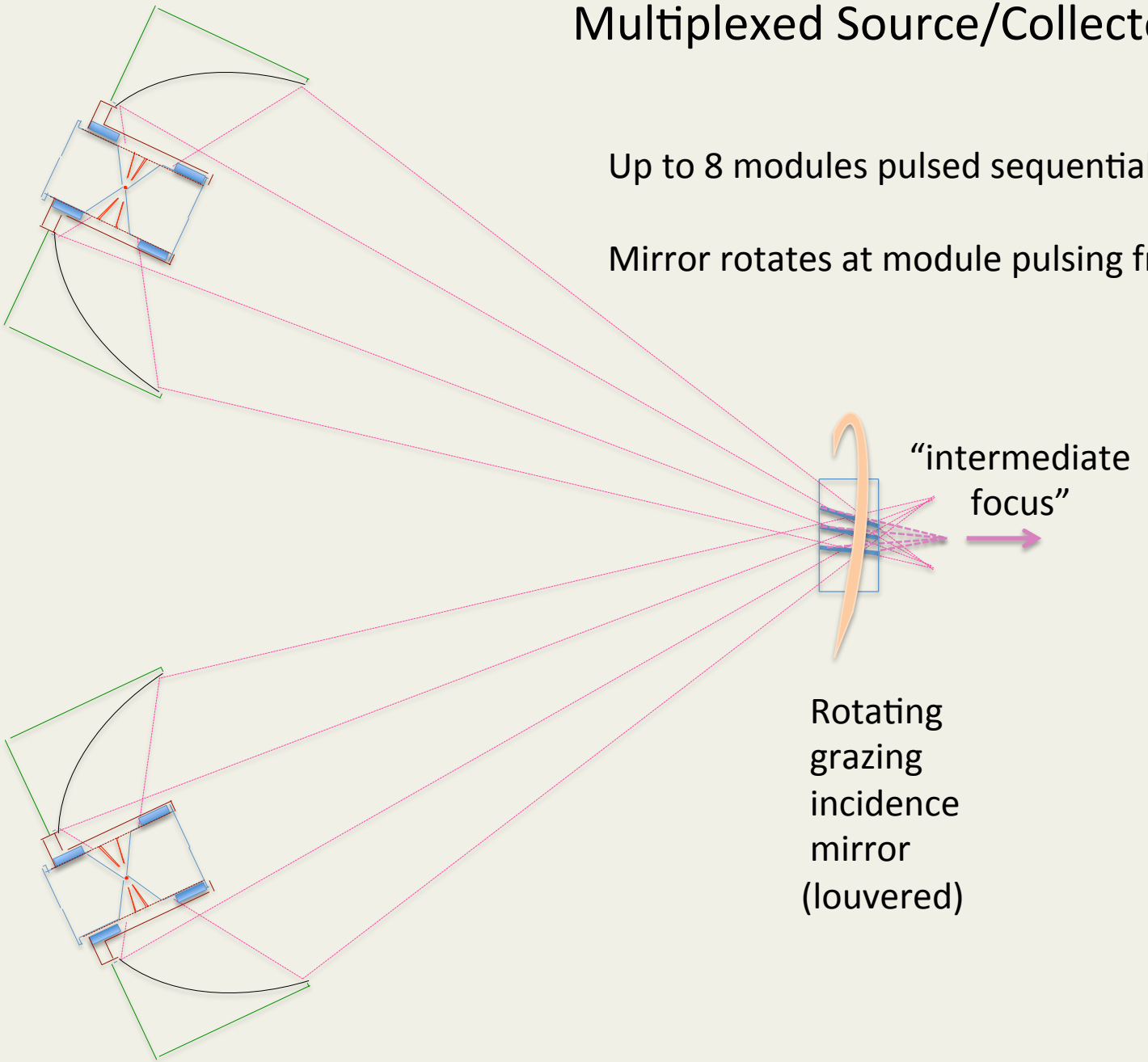
Multiplexed Source/Collector Modules

Up to 8 modules pulsed sequentially.

Mirror rotates at module pulsing frequency



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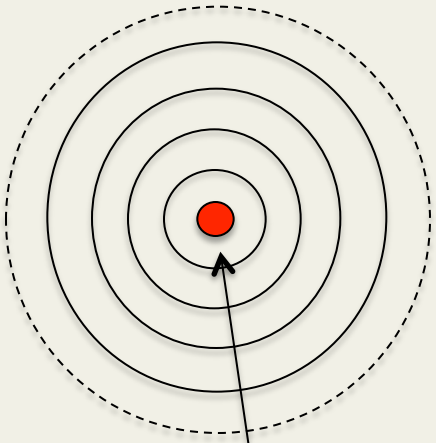
Plasma power is easily handled with lithium via electrode cooling

Tin

1 LOCATION

3 X MORE total power

(6% conversion)

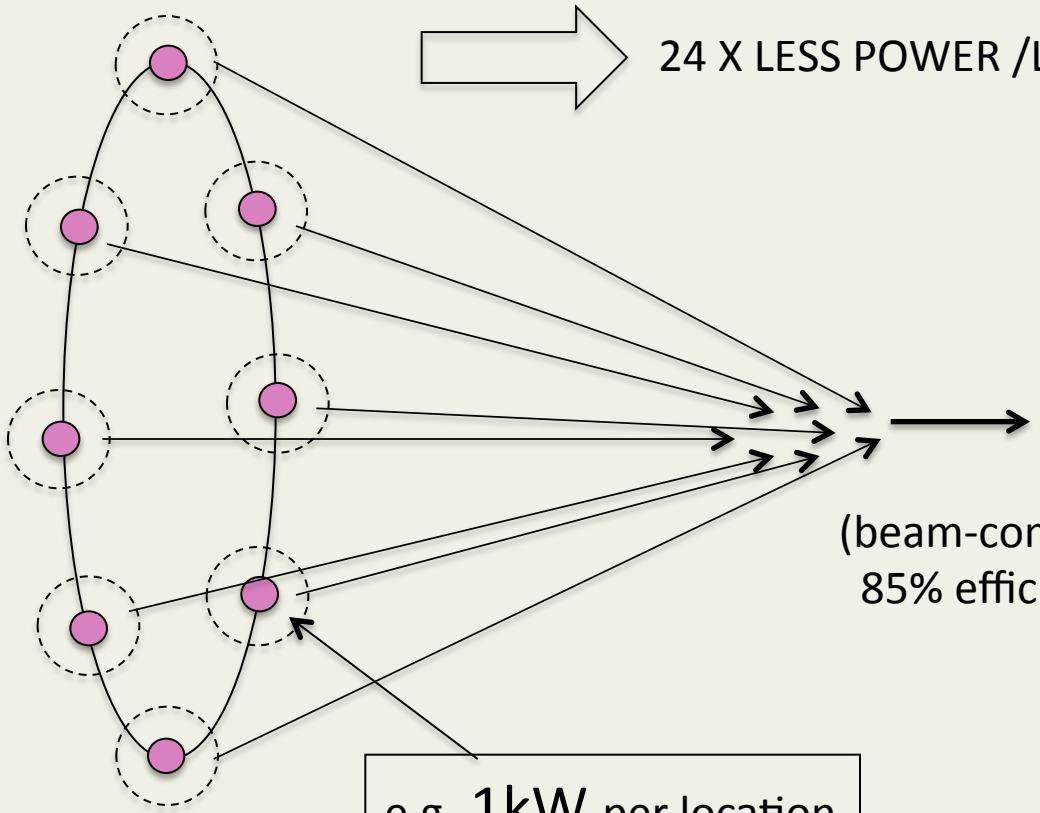


e.g. 24kW

Lithium

8 LOCATIONS, 3 X LESS total power (at 20% conversion)

24 X LESS POWER /Location



(beam-combiner
85% efficient)

e.g. 1kW per location

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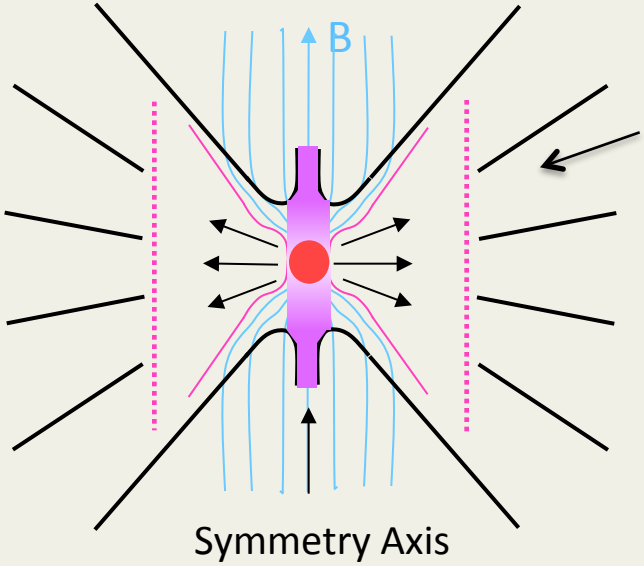
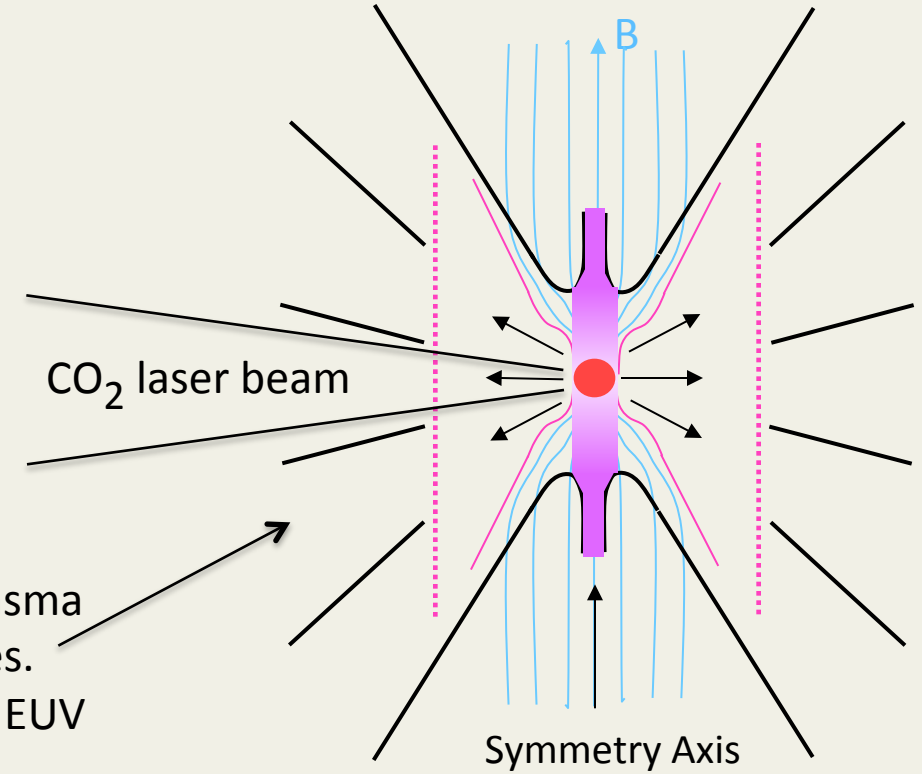
A lithium Z-pinch can be a substitute target when >500W is required



Present direct Li discharge 3 µs 65mJ/pulse 800Hz
- can be multiplexed → 60W IF



Future 1kW Li source * with 2mm plasma stand-off from Li-protected electrodes.
15kW CO_2 laser only, for 1kW usable EUV

*M. W. McGeoch "Laser-heated discharge extreme ultraviolet source"
J. Phys. D: Applied Physics **43**, 105201 (2010)

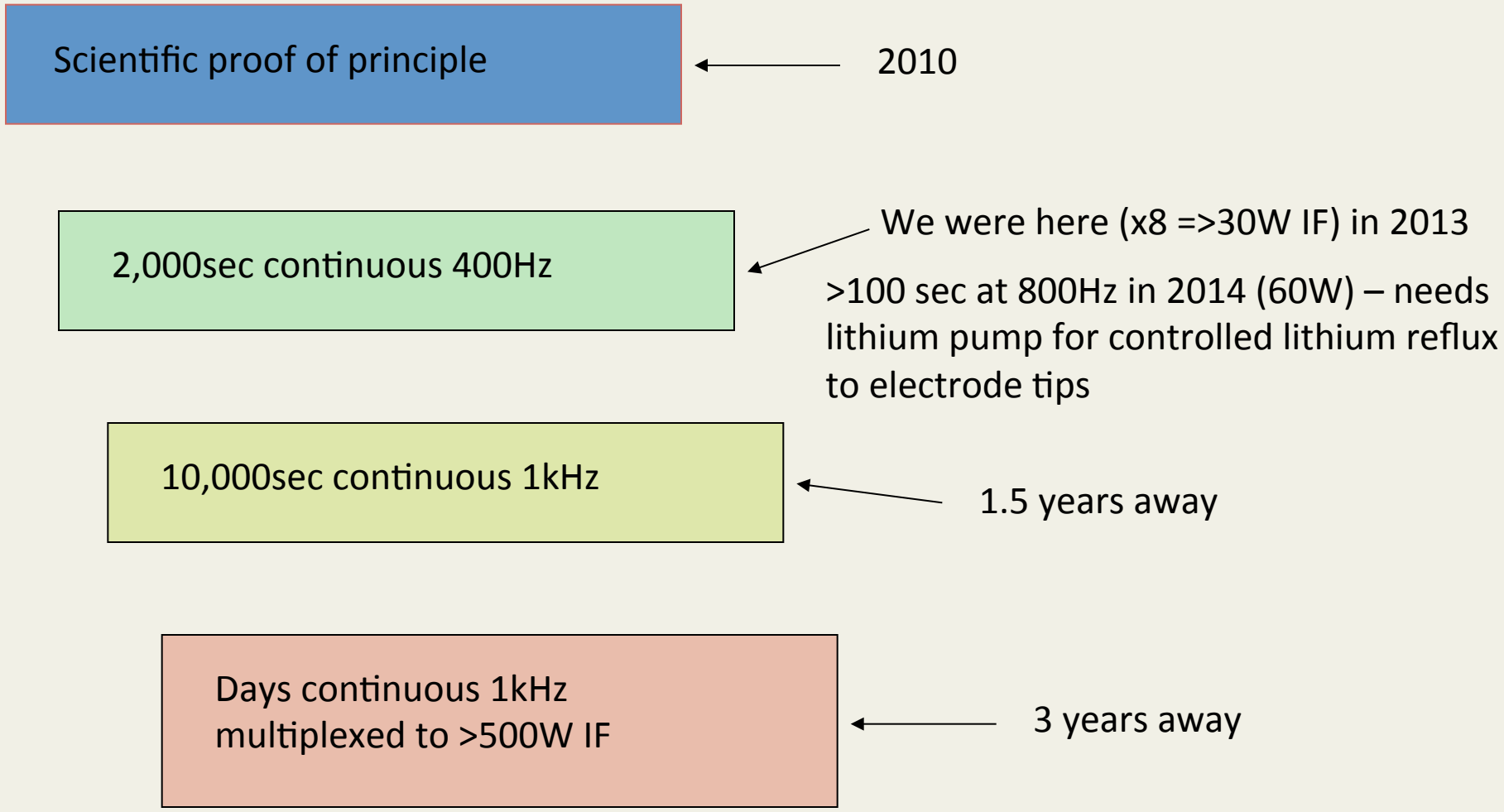
Low Cost of Ownership and Very Low Energy Consumption

500W Source Machine Cost:	$10M
Compact: No Below-Floor Requirement	$10m^2$
Annual Operating Cost, mostly Labor	$1.6M
Electricity Consumption (500W Source)	120kW

Complexity Much Lower than Tin LPP: expect good reliability

Pure Line eliminates Out-of-Band Concerns

Engineering path to >500W Li Source for HVM.
Can be ready in 3 years if development starts now



NOTE: "debris" problem already solved

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